Course: PHYS 541
Term: Fall 2018
Room: Herman Brown Hall 423
Class: TTh 4:00-5:15

INSTRUCTOR CONTACT INFORMATION

Instructor: Matthew G Baring
Office: Herman Brown 366
Email: baring@rice.edu
Office Hours: TW 2:30-4:00pm

COURSE OBJECTIVES AND LEARNING OUTCOMES

Graduate level Radiative Processeses is a core offering on an array of concepts pertaining to the most ubiquitous messenger in the physics world, light. It builds upon a number of the concepts and techniques that are discovered in undergraduate electromagnetism and quantum courses, approaching them with a more sophisticated physical insight and more formal rigor. Relativistic radiative processes will likely be new to the student, and so their treatment will enrich his/her knowledge base. PHYS 541 serves as a focal point of Rice's Physics and Astronomy graduate astrophysics curriculum, yet is an important pedagogy that will equip students whose interests range to atomic and particle physics, and to the chemistry and engineering disciplines. It serves as a grounding for problems they might tackle in their research work. The material presented provides an excellent starting point for those interested in delving deeper into particular radiative mechanisms in plasma physics, electromagnetism, quantum mechanics and particle physics.

Objectives: The goal is to provide students with a basic understanding of many of the important elements of classical electromagnetic and quantum processes involved light, developing a working knowledge of the radiation and scattering of electromagnetic waves. Much of the course is analytic in character and formal theory by necessity. Yet to maintain contact with contemporaneous computational methods as research tools, there will be occasional numerical components in the homeworks. Topics covered include radiative transfer, thermal radiation, special relativity, Larmor formalism, the generation of energetic light by relativistic charges, pair creation, plasma processes, and atomic structure and radiative transitions.

While the emphasis of the course is primarily on astrophysical applications, there will also be sporadic examples from atomic, particle, space and even medical physics in the lectures to elucidate their content. Thus, students will learn how particular concepts can be pertinent to different physics disciplines. They will be taught to think logically and critically about what are reasonable assumptions in physical developments and what are not, and how to evaluate and check derived results. They will also be taught how to think "laterally" by connecting seemingly unrelated concepts to enhance understanding of a given problem or task. This will apply both to analysis methods and occasionally also in developing computational skills.

Learning Outcomes: By completing the course, students will be much better equipped to use electromagnetic radiation concepts in their research, thereby enhancing the Rice graduate study experience. They will be in a position to assess posed problems, suggest algorithms for approaching analytic and computational tasks, test their ideas, and develop efficient strategies for reducing a problem to a tractable form, or an endpoint that will facilitate numerical evaluation. They will receive training in communicating their ideas, hypotheses and understanding of select issues to an ensemble of their peers. This is the essence of the research process: think critically, probe, discover, revise one's perspective and tell the broader community of the results and the path taken to get there, and where to go next. This is invaluable training for an array of professions and potential careers down the line, including industry, business and academia.

REQUIRED TEXTS AND MATERIALS

Radiative Processes in Astrophysics, by George Rybicki and Alan Lightman (2004; Wiley-VCH, Weinheim). This is a staple for astrophysicists that is stylistically derivative of the intellectual approach employed in Landau and Lifshitz' venerated Course of Theoretical Physics.

It is an essential supplement to the lectures as students will be required to read and digest it, and work on problems from it. Notes for course material not contained therein will be provided.

SUPPLEMENTARY SUPPORTING TEXTS

Electromagnetic Processes, by Robert J. Gould (Princeton Univ. Press)
Radiative Processes in Plasmas, by George Bekefi (Wiley & Sons; New York)
The Classical Theory of Fields, by Lev D. Landau & Evgenii M. Lifshitz
(Butterworth-Heinemann; Oxford)
The Quantum Theory of Radiation, by Walter Heitler (Dover; New York)

EXAMS AND PAPERS

The course assessment will consist of approximately five to six problem sheets, cumulatively constituting 40% of the total grade, and in-class lecture presentations by the students counting for 10% of the final grade. In terms of exams, there will be one ***closed-book*** **mid-term exam** during the semester that constitutes 20% of the grade, and an ***oral*** **exam (viva)** at the end of the semester, constituting the remaining 30% of the assessment. This will be like a PhD candicacy exam: closed-book, *potpourri* and at the blackboard.

GRADE POLICIES

All parts of the assessment will be graded on a curve, determined commensurately with the overall performance of past students who have taken this course at Rice.

Late homeworks will automatically receive a 5% reduction in credit, unless an extension has been negotiated with Prof. Baring. Homeworks that are 3-5 days overdue will be reduced by 30% in total credit. Beyond that timeframe, late homeworks will not be graded and score zero.
This policy is because it is (i) not fair to other students to have the return of their homeworks in a timeframe that is delayed by inadvertent tardiness by any student, and (ii) it is not fair to impose logistical constraints on Prof. Baring and any course TA in terms of grading.

Extensions of homework deadlines must be negotiated with Prof. Baring prior to the original deadline, with the student defining good cause for the extension. The negotiated deadline will substitute for the original one in terms of the aforementioned late penalties.

Exceptions to these late policies can occur for extenuating circumstances such as student illness, family illness or emergency. In such cases, it is the student's responsibility to let Prof. Baring know (ahead of time, if possible) what is going on so that he is not "in the dark." The student will need to (retroactively) document the circumstances.

CLASS ATTENDANCE

The purpose of the lectures is to impart knowledge distilled to its essentials on the subject matter of the course and in a manner more efficient than is afforded by merely reading textbooks and browsing Web sites; these important out-of-class learning paths are intended to supplement, not replace lectures. A central ingredient of this classroom forum is leveraging the extensive research experience and science connections of the Lecturer, *and this is best done by attending lectures*. The small average class size underpins an exceptional learning experience that sets Rice apart from many of its peer institutions. **Students should take advantage of this opportunity by habitually attending classes**; their learning curve will be enhanced by such dedication.

ABSENCE POLICIES

Infrequent absences are not a problem. If a student is noted to be absent for an extended period of time, or frequently, the student must communicate with Prof. Baring the reasons of the absence(s). Such cases normally will degrade the efficiency of learning for the student. Again, if there are extenuating circumstances such as student illness or family illness or emergency, accommodations will be made, and Prof. Baring should be informed. Otherwise, concerning any absence, it is the student's responsibility to acquire the pertinent notes/materials to guide their study accordingly. Prof. Baring is under no obligation to provide copies of notes to students who do not attend a given lecture, nor to "re-lecture" such material during office hours.

IN-CLASSROOM TECHNOLOGIES

The learning environment for individuals and the entire class is optimized if it is not disrupted by cell phone activity. Use of cell phones to text or via another mode is distracting to the lecturer and shows inattention on the part of the perpetrator. Moreover it is rude to the lecturer, who invests considerable time in preparing lectures to facilitate the learning of the entire class, and to other students when a distracted moment arises. Dr. Baring **prohibits the use of cell phones in the lecture room**; if a student cannot wait until the conclusion of class to send a text or make a call, he or she should quickly excuse themselves, leave the room, and return only when finished and ready to concentrate on the lecture. Use of laptop computers to take notes is not intrusive and is acceptable to Dr. Baring; use of them to perform telecommunication functions such as Skyping and email is similarly not permitted. **Violations of these rules will lead to the student being asked to leave the classroom for the remainder of the lecture.**

RICE HONOR CODE

In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

The mid-term and scheduled final exam questions are not to be discussed at all with other students, faculty or graders, and are subject to the provisions of the Rice Honor Code. Please verify this by **writing the word pledge and your signature on each exam**. Questions specifically about exams should be directed only to Prof. Baring.

DISABILITY SUPPORT SERVICES

If you have a documented disability or other condition that may affect academic performance you should: 1) make sure this documentation is on file with Disability Resource Center (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with Prof. Baring to discuss your accommodation needs *during the first two weeks of class*.

Any letter from the DRC to the instructor requesting accommodations for the student should be delivered in the first three weeks of semester, so that Prof. Baring can plan accordingly.

SYLLABUS

The detailed syllabus below gives the layout of the course material. For further information, such as scheduling, pointers to related chapters in the Required Text, etc., see the PHYS 541 course web pages at http://spacibm.rice.edu/%7Ebaring/phys541/phys541_syllabus.html .

Fundamentals of Radiative Transfer

Radiative Flux and Specific Intensity
Radiative Energy Density
Intensity Conservation and the Inverse Square Law
Radiative Transfer
Scattering Effects: Diffusion

Thermal Radiation

Blackbody Radiation
Blackbody Thermodynamics/Stefan-Boltzmann Law
The Planck Spectrum and Wien Displacement Law
The Einstein Coefficients
Rosseland Approximation & Mean Opacity
Eddington Two-Stream Approximation

Radiation Fields

Maxwell's Equations
Electromagnetic Waves
Electromagnetic Potentials
The Radiation Spectrum
Polarization of Radiation

Radiation from Moving Charges

The Liénard-Wiechart Retarded Potentials
Radiation Fields of Accelerating Charges
Radiation from Non-Relativistic Particles
The Larmor Formula
Dipole Approximation
Multipole Expansion
Thomson Scattering
Radiation Reaction
Radiating and Undriven Harmonically-Bound Charges
Driven Harmonically-Bound Particles

Special Relativity

Lorentz Transformations
Velocity Transformations
The Doppler Effect
Maxwell's Equations in Covariant Form
Covariant Equations
Transformation of the Electromagnetic Field
Fields of a Uniformly-Moving Charge
Emission of Relativistic Particles
Lorentz Invariants for Radiative Transfer

Collisional Processes

Coulomb Scattering
Non-Relativistic Bremsstrahlung
Bremsstrahlung from Single-Speed Electrons
Thermal Bremsstrahlung
Relativistic Bremsstrahlung

Synchrotron Radiation

Synchrotron Power
The Radiation Spectrum
Generic Character
Cyclotron-to-Synchrotron Transition
Non-thermal Synchroton
Details of Spectrum and Polarization
Synchrotron Self-Absorption

Compton Scattering

Cross Section and Kinematics
Inverse Compton Power: Single Scattering
Inverse Compton Upscattering Spectra
Power-Law Electrons
Repeated Scatterings: Energy Transfer
Comptonization -- Kompaneets Equation
Unsaturated Comptonization

Pair Creation and Annihilation

Pair Creation Threshold
Pair Creation Cross Section and Rates
Power-Law Photons
Annihilation Cross Section and Spectrum

Plasma Processes

Cold Plasma Dispersion
Faraday Rotation
Cerenkov Radiation and the Razin Effect

Atomic Structure

The Bohr Atom
The Schr"odinger Equation
Hydrogenic Solutions
Many-Electron Systems
LS Coupling
Level Splittings
Spin-Orbit Coupling
Zeeman Effect
Ionization Equilibrium: Saha Equation
Structure of Spectral Lines

Radiative Transitions

Semi-Classical Theory of Radiative Transitions
Non-Relativistic Atoms
The Dipole Approximation
Einstein Coefficients and Oscillators Strengths
Selection Rules
Transition Rates
Photo-electric Effect
Radiative Recombination: Milne Relations
Line Broadening Mechanisms

SYLLABUS CHANGE POLICY

This syllabus is a general guide for the course and is subject to change without advanced notice.